OPTICAL DISC STORAGE WITH 2D-DATA-TRACK AND WITH GUARD BAND STORING NON-CONTENT INFORMATION AND READING DEVICE THEREFORE

FIELD OF THE INVENTION

The present invention relates to a storage medium carrying meta-tracks of N (N>1) bit-rows, two adjacent meta-tracks being separated by a guard band of at least one bit-row referred to as guard band bit-row.

The present invention also relates to a device for reading a storage medium that carries meta-tracks of N (N>1) bit-rows, two adjacent meta-tracks being separated by a guard band of at least one bit-row referred to as guard band bit-row.

The present invention applies to two-dimensional optical storage for example two-dimensional Blu-Ray discs.

BACKGROUND OF THE INVENTION

The principles of two-dimensional optical storage are presented in the article "Two-Dimensional Optical Storage" by M.J. Coene, Optical Data Storage May 11-14, 2003 Hyatt Regency Vancouver, BC Canada. As explained in this article, the format of 2D disc is based on a broad spiral consisting of a number of parallel bit-rows that are aligned with each other in the radial direction in such a way that a 2D close-packed lattice results. The lattice can have various forms. However hexagonal lattices provide a higher packing fraction. A guard band of one empty bit-row is located between adjacent turns of the broad spiral.

The channel bits that are written on the disc are of the land type (bit "0") or of the pit-type (bit "1"). A physical bit-cell in the lattice is associated with each bit. The bit-cell for a land-bit is a uniform flat area at land-level. A pit-bit is realized via mastering a pit-hole centered in the bit-cell.

Parallel read-out is realized by using a single laser source that passes through a diffraction grating which produces an array of laser spots that scans the full width of the broad spiral. The light from each laser spot is diffracted by the 2D pattern on the disc and is detected on a multi-partitioned photodetector which generates a number of high frequency signal waveforms. This set of waveforms is used as the input for the 2D signal processing.

The signal processing path from the photo detector to the detected bits comprises: analog-to-digital conversion, pre-filtering, signal alignment, equalization, sample rate conversion and eventually bit detection. As can be seen from Fig.2 of this article, the timing information needed for controlling the sample rate converter is extracted from the content data carried by the broad spiral.

The present invention proposes improvements for a two-dimensional optical storage of the type described in this article.

SUMMARY OF THE INVENTION

A storage medium according to the invention is defined in claims 1 to 3. A device according to the invention for reading a storage medium is defined in claims 4 to 8.

According to the invention non-content information is stored in the guard band separating two meta-tracks (that is two 360° turns of the broad spiral). This non-content information comprises clock data and/or control data that are needed for controlling reading/writing operations from/onto the storage medium. For instance control data comprise: speed control data for controlling the rotation speed of the storage medium, sector marks for defining sectors on the storage medium, address information for navigation through the content, digital right management information, etc...

Preferably, the signal carried in the guard band shall remain relatively regular. The clock data is a regular high-frequency pattern. In order that the regularity of the signal carried in the guard band is not damaged, and to facilitate the discrimination of the control data from the content data carried by the meta-tracks, the control data are preferably low-frequency data. When both clock data and control data are stored in the guard band, the clock data are modulated with the control data for example the clock data are phase modulated or amplitude modulated.

A device according to the invention for reading such a storage medium comprises:

- an optical unit for generating at least N light spots, receiving at least N reflected light spots and generating at least N analog signals associated each to one of said reflected light spots, in order to read in parallel a meta-track and a guard band bit-row adjacent to said meta-track, and

- means for processing at least N of said analog signals in order to recover content information stored in said meta-track and non-content information stored in said adjacent guard band bit-row.

The number of light spots generated by the optical unit depends on the implementation. If only N light spots are used, the non-content information carried by the guard band is derived from the N^{th} reflected light spot (generally referred to as read-out light spot). Alternatively an extra light spot can be used for reading the guard band bit-row. For design simplicity, it may be preferred to add more than one extra light spot. In such a case, the reflected light spot(s) above the N+1 necessary reflected light spots is/are not needed for implementing the invention.

The structure of the processing means depends on the nature of the non-content information carried in the guard band.

When the non-content information comprise clock data, the processing means comprise:

- an analog-to-digital converter for receiving at least N of said analog signals and generating at least N digital signals,
- a phase-locked loop circuit for receiving one of said digital signals that is associated to a light spot that is at least partly reflected by said guard band bit-row such that said digital signal carries said non-content information, and for generating a clock correction signal therefrom,
- a sample rate converter controlled by said clock correction signal, for receiving N of said digital signals and for generating N corrected digital signals,
- a first detection circuit for receiving said N corrected digital signals and deriving therefrom N sequences of bits that correspond to said content information.

The analog-to-digital converter is controlled by a local clock so that the digital signals that are generated by the analog-to-digital converter are to be phase-corrected by the sample rate converter. In this embodiment, the sample rate converter is controlled by a clock correction signal generated by a phase-locked loop circuit from the clock data carried in the guard band.

The frequency of the clock data (referred to as pilot frequency in the following of the description) in the guard band may be equal to the local clock frequency. However this is not required. When the pilot frequency is different from the local clock frequency, the phase-locked loop circuit makes a frequency adaptation. Advantageously the

pilot frequency is chosen equal to the highest possible frequency that occurs in the system (which depends on the form of the lattice) but shall remain lower than the cut-off frequency of the optical unit.

Storing clock data in the guard band is a very simple and efficient way of enabling recovery of the bit clock rate, especially in 2D storage systems where the intersymbol interference between bit-rows of the meta-track is so high that using the traditional zero-crossing clock recovery method would lead to very complex signal processing.

When the non-content information comprise control data in addition to clock data, the processing means further comprise a second detection circuit for receiving said clock correction signal and deriving therefrom a sequence of bits that corresponds to said control data.

When the non-content information comprise control data to the exclusion of clock data, the processing means comprise:

- an analog-to-digital converter for receiving at least N of said analog signals and generating at least N digital signals,
- a sample rate converter for receiving said at least N digital signals and for generating at least N corrected digital signals,
- a detection circuit comprising:
    a) means for receiving N corrected digital signals and deriving therefrom a reference signal and N sequences of bits that correspond to said content information, and
    b) means for receiving one corrected digital signal that is associated to a light spot that is at least partly reflected by said guard band bit-row such that said corrected digital signal carries said control data, and deriving therefrom a sequence of bits corresponding to said control data,
- a time recovery circuit for receiving said reference signal and at least part of said N corrected digital signals, and for generating an time correction signal used for controlling said sample rate converter.

In the absence of clock data in the guard band, the timing information used to control the sample rate converter is extracted from the content data in a classical way. The signal that carries the control data is processed in parallel with the signals that carry the content information through the same circuits.

Storing control data in the guard band is an interesting alternative to track wobbling currently used in some 1D storage systems.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention are further described by reference to the following drawings:

- Fig.1 is a schematic representation of a storage medium according to the invention,
- Fig. 2 and Fig.3 are a detailed view of a portion of the storage medium of Fig.1,
- Fig.4 is a general diagram of a device according to the invention for reading a storage medium of the type described by reference to Fig.1 to 3,
- Fig. 5 is a first example of an embodiment of the device of Fig. 4,
- Fig. 6 is a second example of an embodiment of the device of Fig. 4,
- Fig. 7 is a third example of an embodiment of the device of Fig. 4.

DESCRIPTION OF EMBODIMENTS

Fig.1 shows a storage medium 1. Fig.2 and Fig.3 show a portion 2 of the storage medium 1 in a first and a second larger scale respectively. The storage medium 1 is a disc having meta-tracks T_i forming each a 360° turn of a spiral line 3. As shown in Fig.3, each meta-track T_i comprises N parallel bit-rows $R_1, \ldots, R_N$ that are aligned with each other in the radial direction in such a way that a 2D close-packed hexagonal lattice results. A physical hexagonal bit-cell in the lattice is associated with each bit B_j (j=1 to N). A guard band G_i of one bit-row R_{N+1} is located between adjacent turns T_i and T_{i+1} of the spiral 3. The meta-tracks carry content information (for example audio data and/or video data and associated application data).

According to the invention a signal that carries non-content information is stored in the guard band G_i during the mastering process of the disc. Said non-content information comprise clock data and/or control data.

The tracks are scanned by a radiation beam 4 that enters the storage medium through a transparent substrate (not represented). Multiple light sources are used for scanning in parallel the N+1 bit-rows composed of the N bit-rows of a meta-track T_i plus the one-bit row of the adjacent guard band G_i. For example, the multiple light source comprises a single laser source and a diffraction grating. The diffraction grating must produce at least

N light spots. Preferably the diffraction grating produces at least N+1 light spots, the N+1th light spot being dedicated to the reading of said guard band bit-row.

When N light spots are used, the Nth light spot is used for scanning both the outer bit-row R_N and the guard-band bit-row R_{N+1}. In such a case the signal is deteriorated by inter-symbol interference but, as will be described in more details by reference to Fig. 5, the performances are still acceptable. When desired, better performances can be achieved by using N+1 light spots. When a grating is used to generate multiple light spots from a single laser source, this implies modifying the prior art grating design. When modifying the grating design, it may be easier to add more than one light spot. If the grating generates more than N+1 light spots, the overhead light spots are not needed for implementing the invention. Therefore they may be ignored.

Fig.4 shows a general schematic block diagram of a device according to the invention. The device of Fig.4 comprises an optical unit 10 having a single laser source 11 and a grating 12 for generating N light spots. N reflected light spots are received by the optical unit 10 and detected by a photodetector 13. The photodetector 13 generates N analog signals $A_1, \ldots, A_N$ associated each to one of the reflected light spots. The N analog signals $A_1, \ldots, A_N$ are forwarded to a signal processing unit 14. The photodetector 13 also generates one or more servo control signals Sk that are forwarded to a servo control circuit 15. The servo control circuit 15 controls the optical unit 10. The signal processing unit 14 outputs N bits sequences $Q_1, \ldots, Q_N$ corresponding to the content information carried by the meta-tracks, and optionally one bits sequence Q_{N+1} corresponding to the control data carried by the guard band. The N bits sequences $Q_1, \ldots, Q_N$ are forwarded to a rendering unit 16 that renders the content to the user.

The destination of the optional bits sequence Q_{N+1} depends on the nature of the control data. In Fig.4, the bits sequence Q_{N+1} is forwarded to a processor 18. Depending on the nature of the control data, the processor 18 may generate control signals towards the rendering unit 16 and/or towards a motor unit 19 responsible for rotating the disc 1. For example when the control data comprise speed control data, the processor 18 generates a control signal towards the motor unit 19. When the control data comprise sector marks and/or addressing information, the processor 18 generates a control signal towards the rendering unit 16. The arrow 20 in Fig.4 represents content delivery to the user. The arrow 22 represents user inputs, for example selections within an on-screen displayed menu. The

arrow 24 represents control signals sent by the rendering unit 16 to the servo control circuit 15 upon user input.

The elements represented in dashed-line in Fig.4 are optional elements. Said optional elements are omitted in some of the embodiments of the invention as will be apparent from the following of the description.

Fig.5 shows a first embodiment of the processing unit 14 that is used when the non-content information comprises clock data only. In this example, only N analog signals are generated by the optical unit 10. An embodiment with an additional light spot dedicated to the reading of the guard band (and therefore N+1 input analog signals) will be easily derived from Fig.5 by the man skilled in art.

In Fig.5, the processing unit 14 receives N analog signals $A_1, \ldots, A_N$. The analog signals $A_1, \ldots, A_N$ are input to a analog-to-digital converter 30 operated with a local clock C_L. The N digital signals $D_1, \ldots, D_N$ generated by the analog-to-digital converter 30 are forwarded to a sample rate converter 32. The N^{th} digital signal D_N is also forwarded to a phase-locked loop circuit 33 (optionally after going through a pre-filter 34 for band-pass filtering).The sample rate converter 32 is controlled by a clock correction signal C_C delivered by the phase-locked loop circuit 33. The sample rate converter 32 outputs N phase-corrected digital signals $D'_1, \ldots, D'_N$ that are forwarded to a first decision circuit 36. The first decision circuit 36 delivers the N bit sequences $Q_1, \ldots, Q_N$. For example, the first decision circuit 36 is a maximum likelihood detector, preferably a Viterbi detector.

The optional pre-filter is used for cleaning up the digital signal D_N before it is passed to the phase-locked loop circuit 33. As the clock signal is very well localized in the frequency space, a large part of unwanted signal can be removed by using a band pass filter upstream the phase-locked loop circuit 33. However, it is to be noted that the phase-locked loop circuit in itself is a very efficient band pass filter and therefore using a pre-filter upstream the phase-locked loop circuit is not mandatory.

When only N analog signals are available, the digital signal D_N that is used for generating the clock correction signal is deteriorated by inter-symbol interferences (data cross-talk from the neighbor bit-row). However, the phase-locked loop circuit 33 has intrinsic band pass filtering capabilities such that the high frequency data coming from the neighbor bit-row will be filtered out. This is the reason why the performances obtained by using only N analog signals are acceptable.

Fig.6 shows a second embodiment of the processing unit 14 that is used when the non-content information comprises clock data and control data. In this example, N+1 analog signals are generated by the optical unit 10, one of these analog signals (A_{N+1}) being dedicated to the reading of the guard band. An embodiment with N light spots only, will be easily derived from Fig.6 by the man skilled in art.

In Fig.6, an additional analog signal A_{N+1} is input to the analog-to-digital converter 30 and the analog-to-digital converter 30 generates an additional digital signal D_{N+1} from this additional analog signal A_{N+1}. The digital signal D_{N+1} is input to the pre-filter 34 and forwarded to the phase-locked loop circuit 33. The clock correction signal generated by the phase-locked loop circuit 32 is forwarded to a second detection circuit 39. The second decision circuit 39 output the bits sequence Q_{N+1} corresponding to the control data carried by the guard band.

The nature of the decision circuit 39 depends on the type of modulation used to modulate the clock data in the guard band. For example, if the clock data are amplitude modulated with the control data, the second decision circuit 39 is designed to monitor the amplitude of the clock correction signal C_C in order to recover the control data. If the clock data are phase modulated with the control data, the second decision circuit 39 is designed to monitor the phase of the clock correction signal C_C in order to recover the control data. These examples are not restrictive. Other schemes can be used as well.

Fig.7 shows a third embodiment of the processing unit 14 that is used when the non-content information comprises control data only. In this example N+1 analog signals are generated by the optical unit 10. An embodiment using N analog signals only, where the bits sequence Q_{N+1} is derived from the analog signal A_N will be easily derived from Fig.7 by the man skilled in the art.

In Fig.7, the phase-corrected digital signal D'_1 to D'_{N+1} are input to a decision circuit 48. The decision circuit 48 is of the same type as the decision circuit 36. The decision circuit 48 generates the bits sequences Q_1 to Q_{N+1}. The decision circuit 48 also generates a reference signal C_R that represents the ideal response of the channel (the decision circuit assumes a certain ideal response). This reference signal is derived from at least one of the bit sequences $Q_1, \ldots, Q_{N+1}$ and from the assumed ideal response of the channel. The reference signal C_R is input to a time recovery circuit 50. The time recovery circuit 50 also

receives an actual signal C_M constituted of those of the corrected digital signal $D'_1, \ldots, D'_N$ that are associated with the bit sequences $Q_1, \ldots, Q_N$ used to derive the reference signal C_R. The time recovery circuit 50 derives an error signal (equal to the difference between the reference signal and the actual signal) and generate a time correction signal C_C that minimizes the error signal (this can be done by a zero-forcing loop or an MMSE loop as described in chapters 10.6 and 10.7 of the book "Digital Baseband Transmission and Recording" by Jan W.M. Bergmans, Kluwer Acamedi Publishers, 1996). The time correction signal C_C is used for controlling the sample rate converter 32.

The schematic diagram of Fig.4, 5, 6 and 8 only show the elements that are necessary for the complete understanding of the invention. Other elements not shown in these Figs. may be required in practice for proper operations. For example the signal processing path usually comprises in addition to the above-described elements an equalizer, gain and DC compensation loops, anti-aliasing filters…

With respect to the above-described storage medium and device, modifications or improvements may be proposed without departing from the scope of the invention. The invention is thus not limited to the examples provided.

In particular the invention is not limited to the use of a single laser source in association with a diffraction grating. Other types of multiple light sources can be used, for example a laser array, or a fibre optic arrangement.

Use of the verb "comprise" and its conjugation in the text and in the claims doesn't exclude the presence of other means or steps than those listed.

Use of the article "a" for designating an element doesn't exclude the presence of a plurality of such elements.